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A 3-18 GHz Microwave Signal Generator based on Optical Phase Locked Semiconductor DFB Lasers

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Recently, there has been great interest in optical phase locked loops (OPLLs) with semiconductor lasers for optical generation of microwave signals with high spectral purity [1]-[4]. The use of semiconductor lasers as opposed to solid state lasers, such as the Nd:YAG, is attractive due to their compactness and potential for monolithic opto-electronic integration. A major drawback of semiconductor lasers is, however, phase noise which must be reduced significantly for most practical applications. For this purpose, a wideband OPLL can be very efficient if properly designed [2]. We present the experimental results of a 3 to 18 GHz microwave signal generator based on a heterodyne OPLL with offset phase locked 1.5 μm DFB lasers without external cavities or electrical feedback for linewidth narrowing.

As shown in Fig. 1, the microwave signal generator consists of an OPLL carrier generator and an optical modulator [6]. The OPLL carrier generator consists of a free running transmitter laser (Tx-laser) with a 2 MHz linewidth, an optical frontend, a microwave mixer, a loop filter (lowpass with phase lead correction) and a Current Controlled Oscillator laser (CCO-laser) with a 6 MHz linewidth [5]. The microwave signal generated by the beat of the two semiconductor lasers is compared to the signal from a microwave reference oscillator. The resulting phase error signal is then fed back to the CCO-laser which is forced to track the Tx-laser. This causes a significant reduction of the phase noise of the beat signal. The OPLL is a second order loop with a loop bandwidth, f_z , as defined in [2], of 180 MHz, a loop gain of 181 dBHz and a loop propagation delay, τ_d , of only 400 ps. To our knowledge, these loop data are the best ever reported.

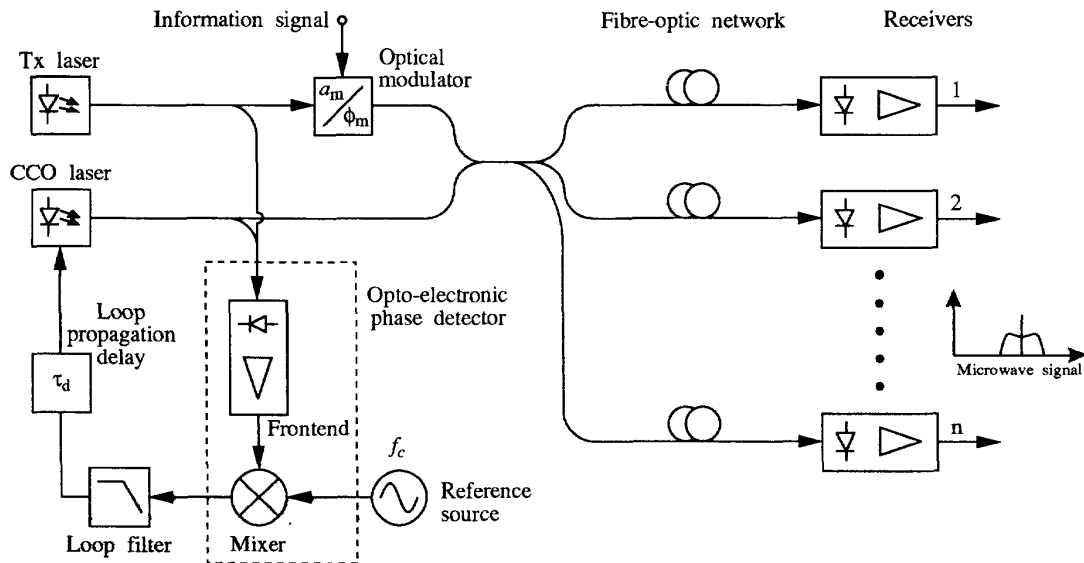


Figure 1: Configuration of the optical microwave signal generator.

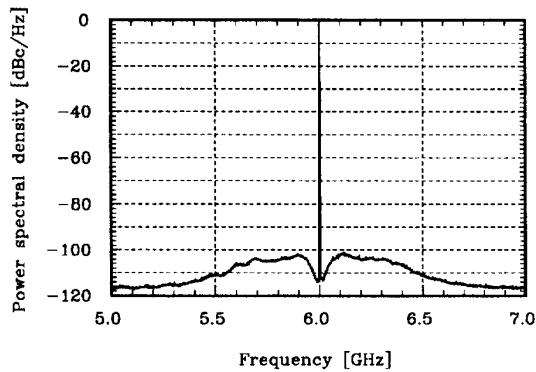


Figure 2: Measured power spectral density of the phase locked beat signal at 6 GHz.

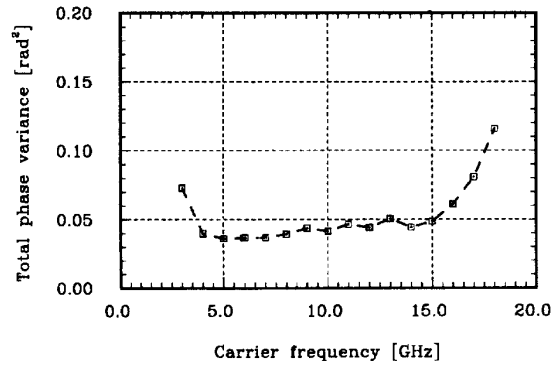


Figure 3: Total phase variance of the generated microwave carrier versus carrier frequency.

At present, the carrier generator operates a continuous frequency range of 3 to 18 GHz determined by the frontend and mixer bandwidths. With MMIC technology it is expected that this range can be extended to 100 GHz. In Fig. 2 the power spectral density of the carrier generated by the phase locked lasers is shown for a frequency of 6 GHz. Close to carrier the spectral shape corresponds exactly to that of the microwave reference oscillator, i.e., sub-Hertz linewidth. The noise level is as low as -110 dBc/Hz @ 100 kHz, -115 dBc/Hz @ 200 kHz to 20 MHz and less than -102 dBc/Hz at all offsets. Of the total signal power 97.7 % is phase locked in the carrier and the total phase variance is only 0.04 rad². This is the lowest value reported for phase locked semiconductor lasers to date. From Fig. 3 it is seen that the phase variance is below 0.05 rad² for carriers from 4 to 15 GHz. The carriers in this range fulfill the phase noise requirements of existing QPSK/DQPSK microwave telecommunication systems. Furthermore, the locked loop operation is very reliable. An acquisition range of 640 MHz has been measured, and the average time to cycle slip, T_{av} , is estimated to 10¹¹ seconds. This yields a probability of less than 0.3 % for one cycle slip within 10 years.

In conclusion, the results clearly demonstrate the feasibility of optical generation of microwave signals with high spectral purity by the use of moderate linewidth semiconductor lasers. As opposed to solid state lasers they are compact and has potential for monolithic opto-electronic integration, which is a very important issue for practical applications.

Acknowledgement

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